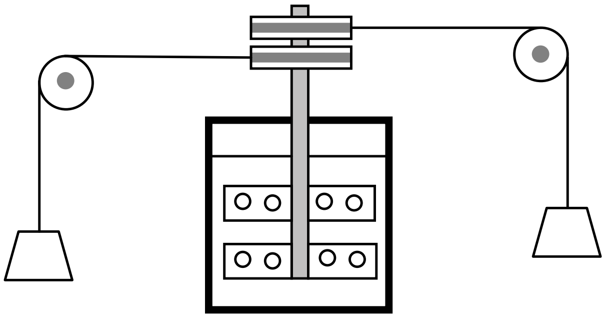
Chapter
3

HEATING AND COOLING

3.0 Ideas of Heat

Early ideas were that heat was an invisible fluid called "caloric" which flowed out of a hot object and into a cold one. This notion remained until an Englishman called Count Rumford noticed that cannons that were being bored out with a drill became very hot. This could not be explained by the Caloric Theory and so a new idea emerged that heat was a form of **energy**: The energy used to drill out the cannon was being converted into heat, according to Count Rumford. It was argued that one form of energy could be converted to another.

Later James Joule set up an experiment to measure the equivalence between mechanical energy and absorbed heat. Weights on strings were allowed to fall, lose their potential energy and stir up the water. The temperature rise of the water was measured and linked to the amount of potential energy lost by the weights. In those days heat was measured on calories and potential energy measured in foot-pounds.

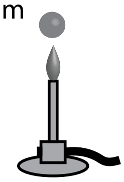


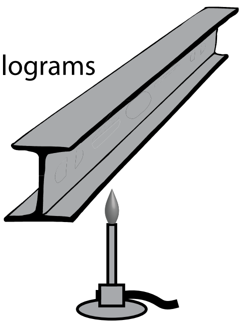
The unit of heat is now the **joule**, which is the same for all forms of energy.

3.1 Temperature

What is the difference between heat and temperature?

To answer this, consider the same lighted Bunsen burner being placed underneath each of these two objects for exactly 1 minute:





At the end of 1 minute, which object possesses the **most heat**?

Which object has the highest temperature?

Answers:

- They both must have had the same amount of heat added as the same bunsen burner was used for the same amount of time.
- The steel ball-bearing will have the highest temperature because there is less of it to heat up (la smaller mass)

Temperature change, then, is a measure of the **concentration of heat** i.e. how much heat has been added to each kilogram of material.

Temperature change ΔT is proportional to the heat per kilogram, H/m (H in joules, m in kg)

Mathematically: $\Delta T \; \alpha \; H/m$ or rearranging, $H \; \alpha \; m \times \Delta T$ (α means "proportional")

Consider the following two objects of the same mass being supplied with the same quantity of heat. Will they both have the same temperature rise?

Because the objects are made of different materials, this will also affect the temperature rise - so allowance must be made in the formula for the **type of substance** being heated. The amount of heat needed to raise the temperature of one kilogram of any material by 1 degree Celsius (or 1 Kelvin degree) is called its **Specific Heat Capacity** (symbol c)

So the final formula for heating an object is $\boxed{H = mc\,\Delta T}$

H = heat supplied (joules)

m = mass of object (kg)

ΔT = temperature change (T2 – T1) in celsius or kelvins

As $c = H/(m\Delta T)$, the units of SHC are J $Kg^{-1}K^{-1}$

For water, the SHC is 4180 J $Kg^{-1}K^{-1}$

The SHC of water is extre mely high – the only substance significantly higher is hydrogen whose SHC is 14.3 kJ kg^{-1} K^{-1}.

Example 1

A girl runs 150 litres of hot water at 40oC into a bath. If this water was heated from 20oC by the heater, what quantity of heat has been absorbed by the water?

Solution 1

m = 150 kg	$H = mc\Delta T$
c = 4180 $JKg^{-1}K^{-1}$	H = 150 x 4180 x (40 – 20) = 12,540,000 J
ΔT = (40 – 20)	H = 12.54 MJ or 1.254×10^7 J

There is also a quantity called Heat Capacity (CH) which does not take into account the mass of a substance.

H = CH x ΔT So to raise 2 kg of water through 5 °C would need
2 x 4180 x 5 joules = 4.181×10^3.

Hence the Heat Capacity of this mass of water is 4.181 kJ K^{-1} (note the units).

3.2 Mechanical Energy Conversion

As Joule showed, potential energy and kinetic energy can be converted into heat energy and cause a temperature rise in another object. For instance, if a brick is dropped from the top of a roof it would become warmer when it hits the ground as the potential energy of the brick on the roof gets converted, firstly to kinetic energy as it speeds up, and finally into heat as it hits the ground.

Potential energy (PE), due to the position of an object above the ground is given by the equation

PE = mgh (mass x gravitational field strength x height)

Kinetic energy (KE), due to the motion of an object is given by the equation

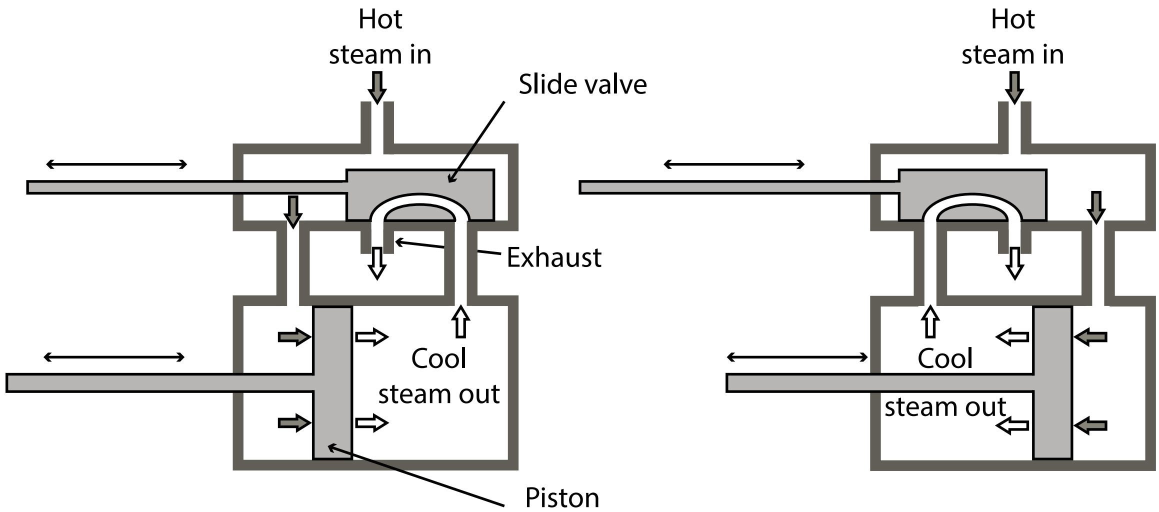
KE = ½ mv^2 (½ x mass x velocity squared)

Electrical energy is the highest form of energy as it can easily be cnverted into other forms: heat, light, mechanical, etc. Heat is said to be the lowest form of energy as it is the most difficult to convert into other forms of energy. For instance, the sea has vast amounts of heat energy but it is not concentrated enough to be useful as the temperature of the sea is low.

However, when the temperature of water is high its heat energy can be easily converted to other forms, such as occurs in a steam engine. When water boils, it expands by about 1600 times and can drive a piston forwards, producing meachanical energy. The workings of any engine relies on the 1st Law of Thermodynamics.

1st law of Thermodynamics

The Steam Engine



This is really a statement based on the Law of Conservation of Energy and says that for any closed system the total energy content of the matter inside is the sum of heat energy (kinetic) plus mechanical work (potential).

As an equation: $\Delta U = Q + W$

So if energy is added to the system (ΔU) this will result in a change in temperature of the matter plus an increase in its potential energy W i.e. work is done by the system.

An example of how this works is shown when a cyclist pumps up his tyres and work is done on the system (air inside the tyre). Where work is done on a system then W becomes a negative value so the formula shows $\Delta U = Q - W$ so for total energy U to be conserved, Q must increase i.e. the temperature of the air in the tyre increases. IConversely, if air is let out of the tyres it cools down.

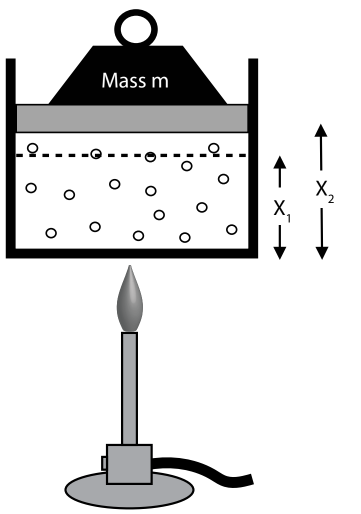
In the steam engine, heat is being added to make the gas heat up and expand and in expanding, kinetic energy is being converted to potential energy and work is done by the gas. So, as W increases the temperature of the gas must decrease.

Work done by gas W = force x distance moved

Pressure P exerted by the mass is given by:

“P = “ “force” /”area” so $mg = P \times A$

Therefore $W = P \times A \times (x_2 - x_1) = P \times \Delta V$



Work done by a gas = Pressure x volume change.

Example 2(a)

A bicycle pump contains 2.50 x 10^{-1} g of air at a temperature of 22.0 °C. In pumping up the tyre an average force of 3.75 N was exerted on the handle and it was moved through a distance of 35.0 cm. Calculate the final temperature of the air in the tyre. (SHC of air = 1.00 x 10^3 J kg^{-1} K^{-1})

Solution 2a

Work done on the air = Fs = 3.75 x 0.35 = 1.3125 J
1st Law of thermodynaamics: 1.3125 = 2.5 x 10^{-4} x 1000 x ΔT
ΔT = 5.25 kelvins

So final temperature = 27.3 °C.

Example 2(b)

A 2.5 kg brick (SHC = 1100 $JKg^{-1}K^{-1}$) is dropped from the roof of a building 30 m above the ground.

Find a) the PE of the brick, b) the KE that the brick has as it hits the ground c) the temperature rise of the brick.

Solution 2b

a) PE = mgh = 2.5 x 9.8 x 30 = 745 J
b) KE gained at bottom = PE lost in falling = 745 J
c) KE converted to heat = mcΔT So 745 = 2.5 x 1100 x ΔT

ΔT = 745/2750 = 0.0267°C

3.3 Power

Power is the **rate** at which heat is supplied. So a heater with a power of 5 watts gives out heat at a rate of 5 joules per second. In 20 seconds this heater would give out 100 J (5 x 20) so the heat given out is given by the formula: Heat = power x time.

Example 3

A family arrives home from holiday and switches on their 3.5 kW water heater, which contains 150 litres of water at 20°C. How long will it be before the family can have a shower if the water needs to be at a temperature of 40°C?

Solution 3

Heat needed to heat the water = 150 x 4180 x (40 – 20) = 1.254 x 10^7 J
Heat supplied = Pt = 3500t = 1.254 x 10^7
t = 1.254 x 10^7/3500 = 3583 s = 59.7 min (almost an hour)

Example 4(a)

A heavy box is being dragged along the floor with a frictional force of 12 kN. The distance the box is dragged is 8 metres. a) How much heat would have been generated from friction? b) If the box has a mass of 8 kg and a SHC of 720 $Jkg^{-1}K^{-1}$, calculate the temperature rise of the box after dragging it.

Solution 4

a) Work done against friction = F x d = 12,000 x 8 = 96,000 J
b) Heat supplied = 96,000 = 8 x 720 x ΔT So ΔT = 16.7°C

Example 4(b)

A heavy box is being dragged along the floor with a frictional force of 12 kN. The distance the box is dragged is 8 metres. a) How much heat would have been generated from friction? b) If the box has a heat capacity of 5760 J K^{-1}, calculate the temperature rise of the box after dragging it.

Solution 4a

a) Work done against friction = F x d = 12,000 x 8 = 96,000 J
b) H = CH x ΔT, so Heat supplied = 96,000 = 5760 x ΔT ΔT = 16.7°C

Specific Heat Capacity Quiz

(Reminder: PE = mgh; g = 9.8; KE = ½mv^2; H = Pt.)

1. A 400 g block of lead (SHC = 130 J kg-1K^{-1}) is being heated up from 20^{o}C to its melting point of 327^{o}C. How much heat was absorbed in the process?

2. A solar heating panel on a roof is used to heat 40 kg of water initially at 22^{o}C, using the sun, which absorbs 750 joules per second. What would the temperature of this water be after 1 hour?

3. A 450 g block of metal is supplied with 11 kJ of heat and its temperature rises by 41^{o}C. What is the SHC of the metal?

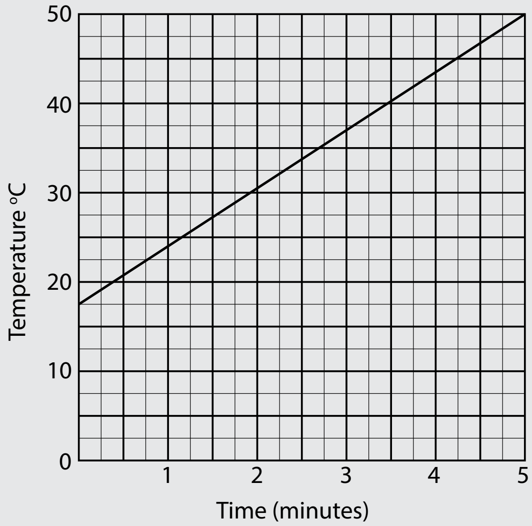
4. A 90 watt heater used to heat a 0.52 kg block of a material for 1½ minutes, during which time its temperature rises from 20^{o}C to 100^{o}C. Find the SHC of the metal.

5. A kettle contains 1.8 kg of water at 25^{o}C. If the element is rated at 2100 W, how long will it be before the water boils?

6. A Bunsen burner is used to heat 250 g of water at 15^{o}C for 4 min. If the Bunsen burner is rated at 200 watts, find the final temperature of the water.

7. A 60 kg athlete takes in 9 MJ of energy from her food per day. If this energy were converted into heat, what would be the theoretical temperature rise of her body if its SHC is 3.49 kJ kg^{-1}K^{-1}?

8. 12 kg of a liquid is heated, using a 900 W heater. The temperature of the liquid is recorded every minute as shown. Use the graph to estimate the SHC of the liquid.



9. A paddle wheel is used to stir 0.5 L of water in a beaker. The wheel is turned by a weight of mass 9.5 kg falling through a height of 2.0 m. After the weight has fallen 50 times the temperature of the water rose by 4.0 °C. Calculate the SHC of water from these data.

10 A 1.8 tonne 4WD travelling at 90 kmh^{-1} is stopped by 4 iron disc brakes (SHC = 440 J $kg^{-1}K^{-1}$), each of mass 500 g. Assuming all the kinetic energy is changed to heat, calculate the temperature rise of each brake with no air cooling.

11. Estimate the difference in temperature of the water at the top and bottom of Niagara Falls (height = 60 m).

12. A building's air-conditioning system recirculates 200 kg of air in one minute with a SHC of 995 J $kg^{-1}K^{-1}$. If the air comes in at 30°C and is cooled to 18°C calculate the heat removed from the air each minute.

13. A candle of mass 12.65 g initially is used to heat 100 g of water at 21°C. When the water temperature has risen to 29°C it was found that the candle mass was now 12.39 g. Calculate the energy contained in 1 gram of the candle wax.

14. In an experiment to find the SHC of lead shot, 100 g was placed in a 50 cm, closed tube and inverted 20 times. Originally the lead's temperature was 18.4°C and its final temperature was 19.1°C. Calculate a value for the SHC of lead.

15. A bullet of mass 9.50 g was fired at a velocity of 250 ms^{-1} at a brick with a mass of 3.0 kg. Estimate the temperature rise of the brick after the bullet had stopped (SHC of brick = 800 J $kg^{-1}K^{-1}$.)

16. 300 g of water was placed on an electric heater for 2 minutes and its temperature rose by 44°C. What would be the temperature rise of 500 g of cooking oil (SHC = 2800 J $kg^{-1}K^{-1}$) placed on the same heater for 1 minute?

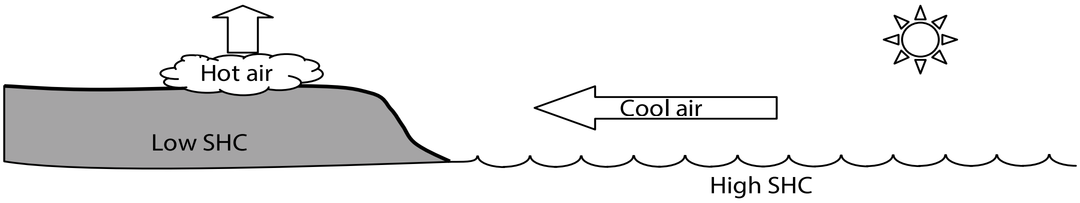
17. A gas heater was used to heat a room of air measuring 3 x 4 x 5 metres. After 5 minutes the temperature of the air (SHC = 995 J $kg^{-1}K^{-1}$) had risen by 15°C. If 1 m^3 of air has a mass of 1.20 kg, find the rate at which the heater is supplying heat, in joules per second.

18. A man making an iron gate in a forge hammered a 750 g piece of iron, which was at 650°C and placed it into a 5 litre bucket of water at 22°C. Estimate the final temperature of the water, assuming that all the heat from the iron (SHC = 440 J $kg^{-1}K^{-1}$) was transferred to the water without any boiling (See section 3.8).

3.4 Climate considerations

The difference between the SHC of land and water is the cause of breezes on the coast and is responsible for the wind flow patterns around the Earth.

Imagine the land and sea being heated in the early morning

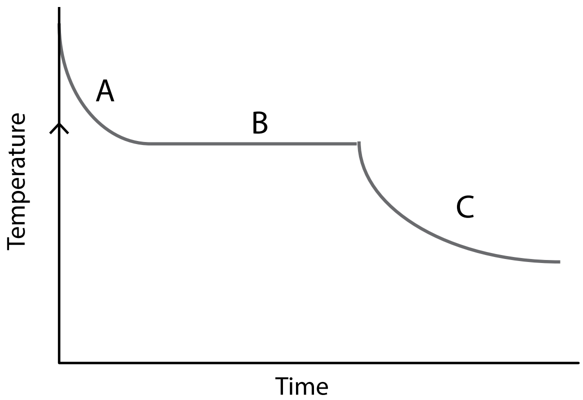


Land has a low SHC and water has a very high value, which means that during the day the land will get hot whilst the sea's temperature will stay virtually the same. Hot air will rise above the land due to convection currents, leaving an area of low pressure (less air). Air will then move in from the sea where the pressure is higher and cause a **sea breeze**. When the hot air from the land rises to the upper atmosphere it cools and falls down out at sea, creating a cycle of moving air. All winds over the surface of the Earth are produced in this way. At night the air flow reverses (land breeze) because the sea is now warmer than the land.

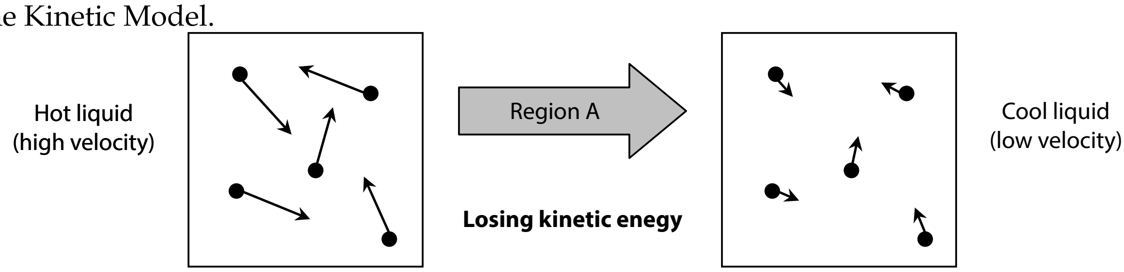
3.5 Latent heat

If a beaker of water is heated continuously with a Bunsen burner its temperature continues to rise until it gets to 100°C. If heat is still being supplied, why does the temperature not rise any further? The heat energy is obviously being used to do something else but not for changing the temperature. This hidden (latent) heat is being used to **change the state** of the water from liquid to vapour.

When solids are cooled (e.g. wax) the shape of the cooling graph has 3 main regions, as shown on the right.

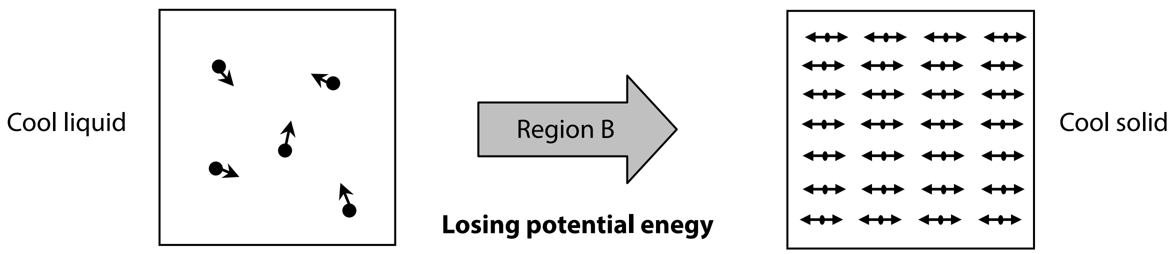


Region A is where the hot liquid wax is cooling and losing temperature, but in region B the wax is hot and not losing temperature. Why? How can a hot object stay at the same temperature? The heat loss seems to be "hidden". The following diagrams illustrate the situation in terms of the Kinetic Model.



High temperatures means that the molecules are moving with a high average kinetic energy, so cooling involves losing kinetic energy and therefore temperature.

In cooling, the molecules also move **closer** to each other and consequently the intermolecular forces become greater.



At the start of region B energy is given out as the molecules move closer to each other and lose potential energy so some liquid starts to become solid. More and more potential energy is lost as more molecules move closer together but their **temperature stays the same**. The heat given out during cooling is called latent heat (hidden heat).

The heat absorbed when a solid melts is called latent heat of fusion and the heat absorbed when a liquid boils is called the **latent heat** of vaporization.

Specific latent heat of fusion (SLHF, Lf) of a substance is the heat needed to melt 1 kilogram of the substance without a change in temperature.

Specific latent heat of vaporisation (SLHV, Lv) of a substance is the heat needed to boil 1 kilogram of the substance without a change in temperature.

Values: SLHF of ice = 3.34×10^5 J kg^{-1} (= Lf)
SLHV of water = 2.25×10^6 J kg^{-1} (= Lv)

Example 5

How much heat is needed to melt 50 g of ice cubes without a temp change?

Solution 5 H = mL = $0.05 \times 3.34 \times 10^5 = 1.67 \times 10^4$ J

Example 6

A saucepan of water at 100°C is heated on a stove that gives 35 kJ of heat per minute. After 3 minutes:

a) How much heat has been supplied to the saucepan?

b) How much water has boiled off?

Solution 6 a) 35 kJ in 1 minute = 3 x 35000 J in 3 minutes = 1.05×10^5 J

b) H = mLv so m = H/Lv = $1.05 \times 10^5 / 2.25 \times 10^6$ = 0.0467 kg boiled off.

Example 7

An aluminium can of mass 270 g contains 150 g of water at 25 °C. The can of water is heated by a Bunsen burner that supplies 14.6 kJ of heat. Calculate the final temperature of the aluminium can of water (SHC of aluminium = 880 JKg^{-1}K^{-1})

Solution 7 The heat supplied is shared between the can and the water so they both have the same change of temperature.

$$H = (m_{Al} \times c_{Al} \times \Delta T) + (m_w \times c_w \times \Delta T)$$

$$1.46 \times 10^4 = (0.27 \times 880 \times \Delta T) + (0.15 \times 4200 \times \Delta T)$$

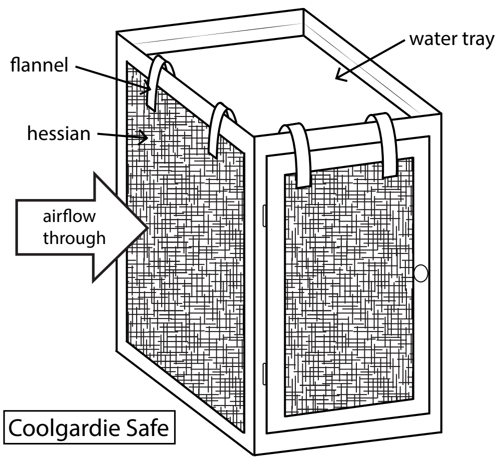
$$= 237.6\Delta T + 630\Delta T = 867.6\Delta T$$

$$\text{So } \Delta T = 1.46 \times 10^4 / 867.6 = 16.8^{\circ}C$$

3.6 Refrigeration

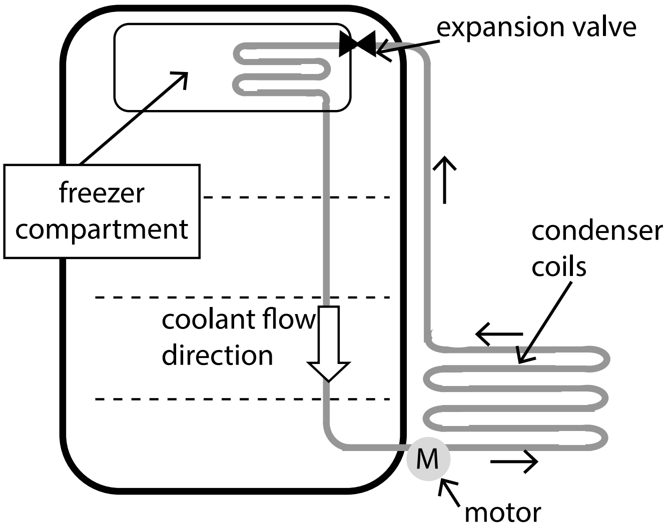
A very simple form of food cooler was used by the old gold miners out in the bush from a box and some wet cloth supplied with water from a reservoir on top.

This device relied on natural airflow and was called the Coolgardie safe. As the breeze flows through the wet hessian sacking it forces the water molecules apart to gain PE. This PE is obtained from the KE of the water. The KE of the water reduces and hence its temperature drops, cooling the air and the food inside the safe. This is still the principle used today for evaporative air conditioners.



Coolgardie Safe

The Refrigerator



Instead of water, a gas is now used which has a much lower boiling point (volatile) and can be compressed easily into a liquid, using a pump.

This volatile liquid is used as a refrigerant inside the tubes. This liquid is allowed to boil by passing into a low pressure area through the expansion valve.

The latent heat needed to boil the refrigerant is extracted from the air in the freezing compartment, so the air cools. The gaseous refrigerant then moves down and is compressed into a liquid once again outside the fridge.

Latent heat is given out in the process, which is released in the condenser coils. These have a large area and are painted black to transfer heat efficiently because they get hot.

Evaporative air conditioners work in the same way as the Coolgardie safe and refrigerative air conditioners work as the refrigerator does with air constantly flowing through what is the freezing compartment area. The advantage of refrigerative air conditioners is that they will still work in humid climates whereas with evaporative air conditioners the water cannot easily evaporate into air if it is already saturated with vapour.

3.7 Interconversion of energy

Energy can neither be created nor destroyed. It can only be converted from one form to another.

Forms of energy are: **Potential, Kinetic, Heat, Light, Sound, Electrical, Magnetic, Nuclear.**

e.g The energy conversions of a car going up a hill:

LIGHT → CHEMICAL → HEAT → KINETIC → POTENTIAL

Sun — petrol — heat — movement — up-hill

The sun made plants grow in the past and these decayed over millions of years to become oil. This was burnt in the engine to produce heat (hot air), which expanded to move the wheels (KE). As the car went up the hill, KE was converted to PE.

Interconversion calculations

Example 8

A car of mass 1000 kg, moving at 30 m s^{-1} is stopped by 4 disc brakes, each made of iron and of mass 3.0 kg. If the SHC of iron is 440 J $kg^{-1}K^{-1}$, find the temperature rise in the brakes after braking.

Solution 8

Kinetic energy of car = $\frac{1}{2} mv^2 = 0.5 \times 1000 \times 30^2 = 450$kJ

If temp rise is ΔT then $450000 = 4 \times 3 \times 440 \times \Delta T$ so $\Delta T = 85.2°C$

Example 9

A 2 kg block of lead is dropped from a helicopter to the ground 500 m below. Find the temperature rise if the SHC of lead block = 130 J $kg^{-1}K^{-1}$.

Solution 9

PE of the block = mgh ($g = 9.8\ m/s^2$) = $2 \times 9.8 \times 500 = 9800$ J

If temp rise is ΔT then: $9800 = 2 \times 130 \times \Delta T$ so $\Delta T = 37.7°C$

3.8 Mixing Hot and Cold Objects

When a hot object comes into contact with a cold object heat becomes transferred from one to the other until they both reach the same temperature. The principle involved with solving the mixing problems involves the Law of Conservation of Energy:

Heat given out by the hot object = Heat taken in by the cold object

Example 10

A 50 g block of copper (SHC = 390 J $kg^{-1}K^{-1}$) is heated to 200°C and transferred to a beaker containing 200 g of water at 20 °C. What is the final temperature after mixing?

Solution 10

Let the final temperature of the water and metal = T °C

Heat lost by the hot copper = $mc\Delta T$ = 0.05 x 390 x (200 – T) → 3900 - 19.5T

Heat gained by the water = 0.2 x 4180 x (T – 20) → 836T – 16720

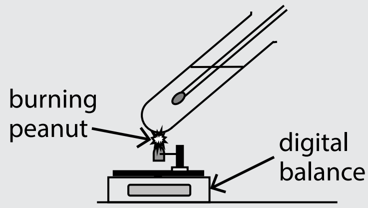
20620 = 855.5T so T = 24.1°C

Heat Calculations Quiz

1. A burning peanut is suspended on a digital balance in an experiment to find the heat content of peanut oil. It is used to heat up a test-tube full of water whose temperature can be measured with a digital thermometer.

The following experimental results were obtained:

Mass of water used	=	32.2 g
Initial temperature	=	17°C
Final temperature	=	31°C
Time of heating	=	68 s
Initial mass of peanut	=	2.89 g
Mass of peanut after burning	=	2.33 g



a) Find the heat gained by the water

b) Find the energy obtained from each gram of peanut oil

2. 60 g of boiling water are poured into a cup containing 150 g of cold tea at 15°C. What would the approximate temperature of tea be after adding the hot water? (Assume the specific heat capacity of tea to be the same as water = 4200 J kg^{-1} K^{-1}).

3. 30 g of crushed ice at 0°C are dropped into 320 g of water at 70°C.

What would the overall temperature of the mixture be immediately after the ice has melted?

4. A pipe from a Canadian steam boiler breaks so the steam comes out and melts the ice around it. If 25 g of steam emerges from the pipe per second, how much ice would have melted before the pipe was repaired 5 minutes later?

5. 1.85 kg of copper shavings were heated to 400°C and then transferred to 620 g of water at a temperature of 29°C contained in a polystyrene bowl. What mass of water boils away?

6. 55 g of crushed ice at –5 °C are transferred into 160 g of water at 65°C. Calculate the temperature of the mixture after mixing (SHC of ice = 2100 J kg-1 K^{-1})

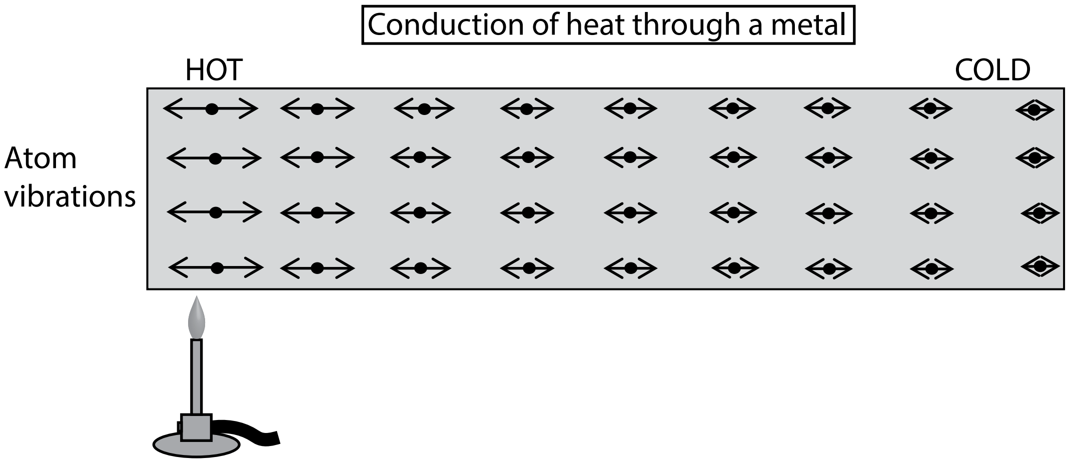
7. A 70.0 kg athlete runs up a mountain path ascending 500 m in a race. Assuming that his body temperature remains the same at 38.1°C, estimate the mass of water evaporated as sweat during the race. (Hint: water must rise in temperature to 100°C then boil)

3.9 Heat Transfer

There are 3 main methods by which an object loses heat: Conduction, Radiation and Convection

Conduction

The molecules of a hot solid are in constant motion – vibrating back and forth in the crystal lattice with vibrational kinetic energy. Gradually this KE gets passed on to the adjacent atoms so that they also become hot. The atoms also move further away from each other to produce expansion in the length and width of the solid.



Some materials can pass their heat energy on better than others – these are good conductors. Where atoms are widely spaced (e.g. gases) the transfer will be very poor.

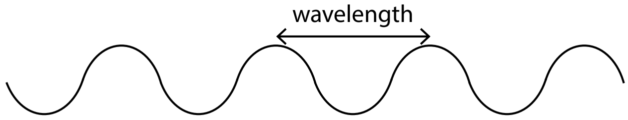
Place the following materials in what you think is the correct order of conduction from Best to Worst:

GLASS STEEL SEAWATER VACUUM COPPER

(Answer: Copper, steel, glass, seawater, vacuum)

Radiation

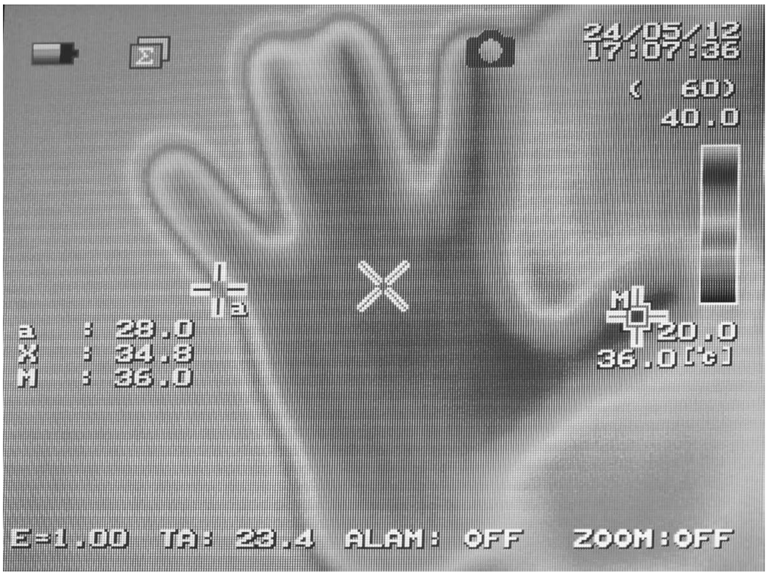
Any object which is hot emits heat rays of varying wavelengths. The lower the temperature the longer the wavelength.



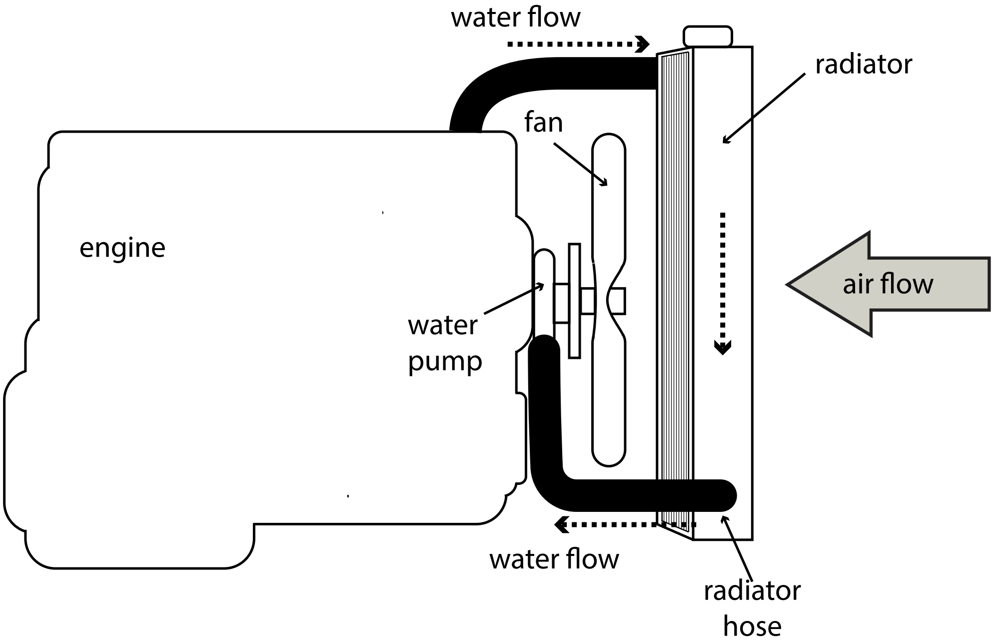
Infrared heat rays are about 1 millionth of a metre long and will make you feel warm if they strike your skin. Hotter objects give out visible light: 800°C will be red hot, while >1000°C will be white hot (more blue light).

Insects like mosquitoes can find animals in the dark by sensing their infrared radiation and ballistic missiles "lock on" to the exhaust IR radiation from a jet engine in order to follow and hit it.

This photograph was taken with an infrared camera which displays the difference in temperature in different parts of the hand. The thumb and forefinger are at a higher temperature than the palm.



Car Cooling System



The large amount of heat generated in a car engine has to be removed otherwise the engine would overheat and seize up (the pistons become melted into the cylinders).

Heat is transferred from the engine to the water surrounding it and pumped to the radiator at the front where fast-moving air can flow through it as the car moves forwards. Hot water is fed from the engine block to the radiator and the car heating system by means of rubber hoses, which allow for movement of the engine whilst it is running.

Air still needs to circulate even when the car is stationary, so a rotating fan pulls the air through the radiator constantly. The heat in the hot water jacket can be used in the winter to heat the interior of the car, using a heat-exchanger.

Conduction occurs in the radiator as it is made of thin copper tubes that allow heat to pass easily through to the outside where the air rushes past these tubes.

Convection carries some of the heat away as the hot air next to the radiator rises.

Radiation from the radiator, in the form of infrared rays, also removes radiant heat and so the radiator is painted black to make this transfer more efficient.

Radiation experiment

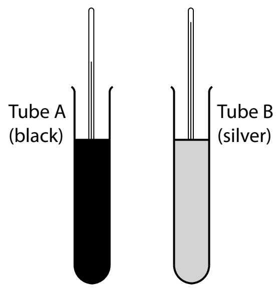
Some colours make a hot object cool down faster than others by allowing more radiation to occur. This experiment is designed to compare the cooling rates of a black test tube with a silvered one.

The **independent variables** that are controlled are:

same temperature;

same volume of water; same surface area of tube;

same position in the room for airflow.



The Independent Variable changed is the surface colour and
the **dependent variable** measured is the final temperature of the tubes.

Procedure

Pour the same amount of boiling water into each tube

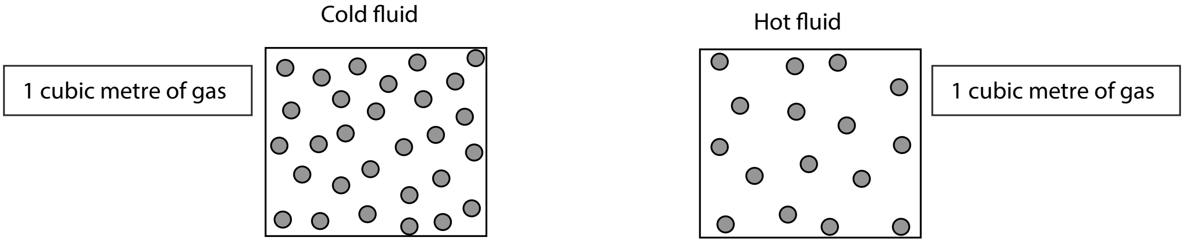
Take readings of each tube for 10 minutes and record the final temperatures of each tube.

Results: The black tube had a final temperature of 81°C and the silver tube was at 92°C.

Conclusion: Heat is radiated at a faster rate from a black hot surface than a silver hot surface.

Convection

As the molecules of a fluid (liquid or gas) get hot they move faster and the average distance apart increases.

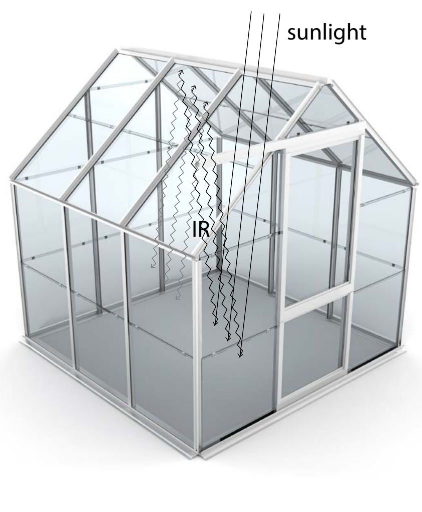


If 1 m^3 of liquid is heated, the gas expands and so less mass of liquid is contained in the cubic metre. This means that the **density of the liquid will decrease** (D = m/v). Less dense liquids float on more dense ones, so a hot liquid will rise. This is the cause of currents in the sea and wind systems around the Earth.

The same thing happens with gases, so a hot gas will rise and float above a cold gas. Hot air balloons work in this way – the large amount of hot air causes the balloon to float above the cooler air. The cruising height of the balloon can be adjusted by weights attached to the balloon and by heating the air more with a burner to rise more.

3.10 The Greenhouse

A greenhouse is used to grow plants quicker, particularly in colder countries. Sunlight comes in through the glass and strikes the floor. This energy is absorbed and heats up the ground, which will then emit heat rays (infrared or IR). When these IR waves strike the glass walls they cannot go through as glass is not transparent to IR, which means the heat rays are trapped in the interior. Even when the outside temperature is low, it can become quite warm inside a greenhouse if the sun is shining.



Global Warming

The **Greenhouse Effect** is where the Earth seems to act like a greenhouse due to an outer layer of greenhouse gases (CO_2 and methane) that are trapped in the upper atmosphere. The Earth heats up due to the sunlight falling on it and therefore emits IR rays towards the sky. The theory is that this IR becomes absorbed by the upper greenhouse gas or reflected downwards again, keeping the heat in – just like a greenhouse.

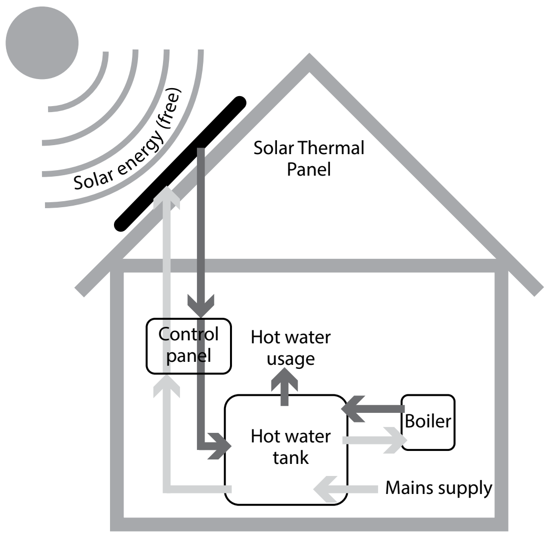
If the average temperature of the earth rises by only a few degrees it will cause massive melting of the polar ice caps, so many countries are now trying to limit the greenhouse gas emissions by switching more of their energy generation to Renewable systems, such as Solar panels, Hydroelectric generators, Wind and wave turbines and Geothermal heating plants.

Solar panels

These are of two types: a) ones that absorb the sun's energy to heat water for domestic use and b) ones that generate electricity from sunlight using solar cells.

a) Solar Thermal Panels

These are installed on the roof and use a radiation collector housed in a mini greenhouse on the roof to trap the sun's rays. The collector pipes are painted black and made of copper to conduct the heat to a stream of water running through them.



b) Photoelectric cells.

Many houses today can be seen with solar panels on their roofs as these can generate electricity directly from sunlight and save power usage. Photovoltaic cells are made of semiconducting silicon sheets. When light strikes the cell, the absorbed light is transferred to the semiconductor atoms where the energy causes electrons to be released and generate a current.

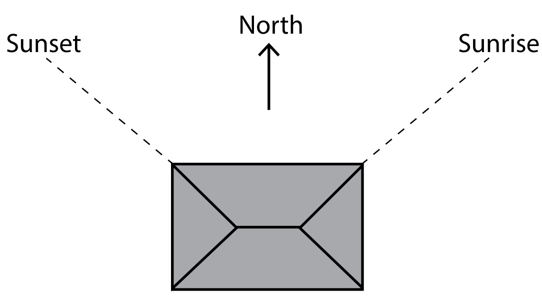
Passive solar design of buildings

With the current concern over making house designs more 'Green" all new houses built must have good insulation and use other new techniques for conserving energy. Traditionally we have used heating systems in the winter and cooling systems in the summer, just so the temperature inside a house remains fairly constant but well-designed homes can get much closer to achieving these energy saving ideals.

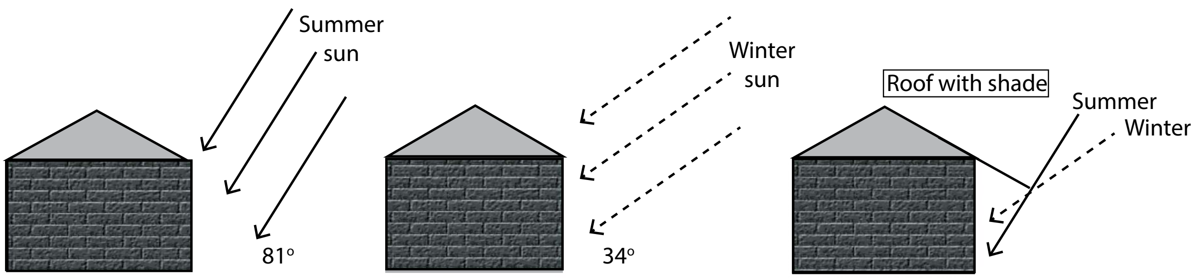
The 5 principles for passive solar design houses are:

- Orientation
- Shading
- Ventilation
- Thermal mass
- Insulation

The **orientation** of a house should be with its rear facing north so as to allow the main glass area to receive the most sunlight. In Perth sunlight delivers 600 W power on each square metre of ground in mid-summer.



Sunlight can help heat the house in the winter without electricity, and also correct **shading** can prevent the house from heating up excessively during summer.

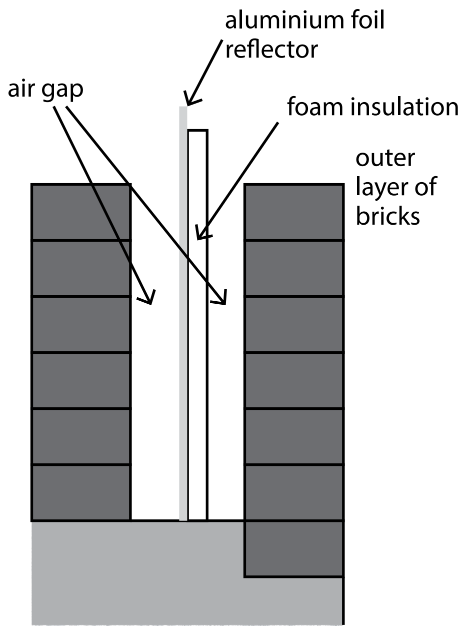


When a shade is attached to the back of a house with the correct amount of overhang then in the summer the rays cannot reach the house but in the winter they can, meaning that the house can be heated by the sun's rays when it is cold in the winter months.

It is essential that the windows in a house are hinged from the top so rain cannot get in when they are open but natural breezes can still **ventilate** the house.

If a house has a large **thermal mass** (large heat capacity) then it can absorb a large amount of heat without its temperature rising very much. Also, when this mass becomes warm it would take a long time for it to cool down and hence the internal temperature of such a house would be very resistant to changes in temperature. In some newly designed "green" houses they have a large mass of concrete (usually as rubble) as the core of the house which "holds' the heat absorbed during the day in winter and retains its low temperature mass in summer when the outside conditions are hot.

These days new houses are, by law, well insulated by means of: double glazed windows; insulated ceilings and double brick (cavity) walls. These methods cut down heat transfer from conduction, convection and radiation effectively.

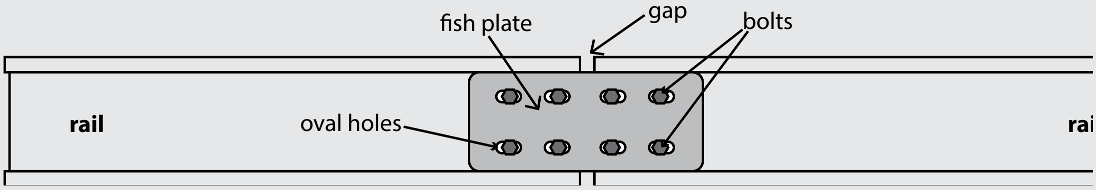


Modern cavity wall design

Heat Transfer Conceptual Quiz 1

1. Steam pipes from boilers always have "U"-shaped bends in them every 10 m or so. This is because the pipes become very hot. Explain why these bends are necessary.

2. Railway lines are joined using "fish plates" shown below. Comment on this method of joining (as opposed to welding) and why it is necessary.



3. Bimetallic strips are used in fire alarms — when the temperature gets high an electrical circuit is turned on to sound a bell. Draw a diagram to show how the bimetallic strip is arranged to make the alarm sound.

4. On a cold day, if you touch a brass doorhandle it feels cold, whereas the wooden door doesn't. Explain this.

5. Tramps in London sleep out under bridges when the temperature is below zero. You find that they wear as many layers of clothes as possible and stuff their trousers with newspaper. Explain the physics principles here.

6. When long-distance runners have finished their race they are covered with a silver space-blanket. Explain the principles of this blanket and how it helps athletes and people suffering from exposure.

7. Racing motorcycles have their engines painted black. Explain the logic of this.

8. People who live in the tropics often wear white clothing. Explain why this is so.

9. Explain the design features that allow vacuum flasks to keep liquids hot.

10. The smaller an animal is, the faster it radiates heat compared with larger animals. Do a calculation using a simple shape, such as a cube; to show that the smaller it is the larger its surface area is relative to its volume.

Heat Transfer Conceptual Quiz 2

Conduction

1. When a student touches the metal tap in the lab he remarks that it feels colder than the bench top. Discuss this phenomenon. [3 marks]

2. Surfers use wet-suits in the winter. How do these work? [3 marks]

3. Eskimos dress using lots of layers of woolly or furry underclothes. Explain how these keep them warm. [3 marks]

4. House roof spaces have layers of Pink Batts laid above the ceiling. Explain the use of these. [3 marks]

Convection

5. Why is the freezing compartment of a refrigerator (ice box) always at the top of the fridge cabinet? [3 marks]

6. In summer, the Fremantle Doctor breeze always comes in about 11 am which helps to cool Perth down. Explain why this breeze is generated. [5 marks]

7. In summer a girl notices that when she swims in the pool on a hot day that the water is always warmer on the surface. Explain why this is so. [3 marks]

8. A wood fire in a house, when alight, always draws in air from the room and the smoke outside is seen to rise up vertically. Explain these observations. [3 marks]

Radiation

9. In hot countries, such as Africa, many houses are painted white.

Why is this? [2 marks]

10. A boy walking on the road in bare feet notices that his feet are burning hot when standing on the tar but cooler when on the concrete pavement.

    Explain this. [3 marks]

11. Solar panels on a roof heat up water for use in the house hot water system. Explain why they are always black and facing North on the roof.

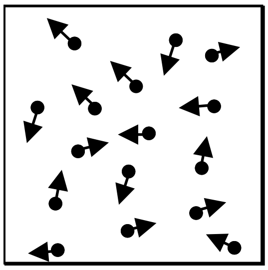
    [3 marks]

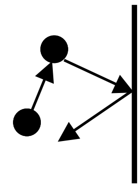
3.11 The Kinetic Theory of Gases

The Kinetic Theory is used to explain how moving atoms of gas produce a pressure and thereby provides an explanation of the gas laws.

In the Kinetic Theory all gas atoms are extremely small compared to the volume they occupy and are each moving at high speed in constant, random motion.

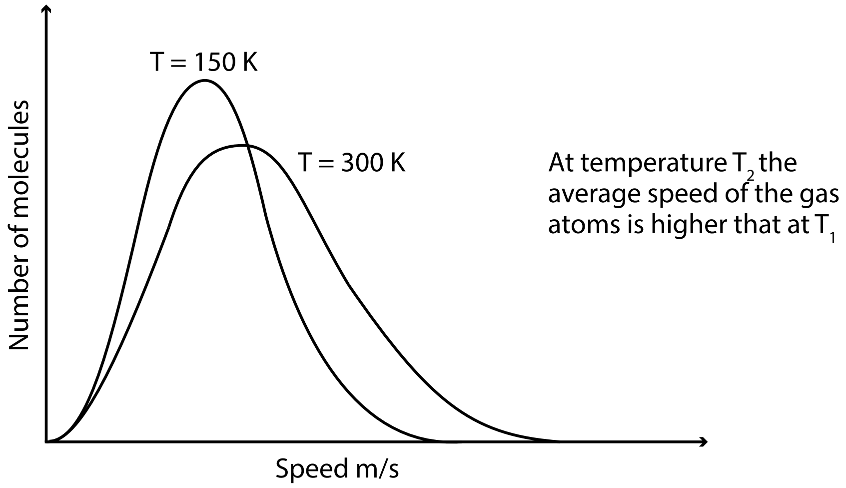
As they move, they are constantly colliding with other atoms and the walls of the container.





Atom moving at random and colliding with the wall to create a force and hence presure.

The distribution of atomic speeds follows the graph shown below.



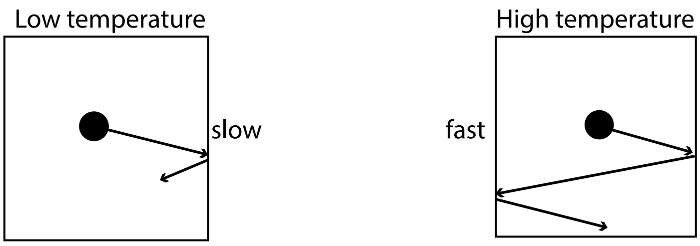
The number of gas atoms colliding with the container walls per second is what creates the force on the walls and hence the pressure of the gas.

Temperature link to Pressure (Volume remaining the same)

If the temperature of the gas in the box rises, the average speed of the atoms rises and therefore the number of collisions per second will increase.

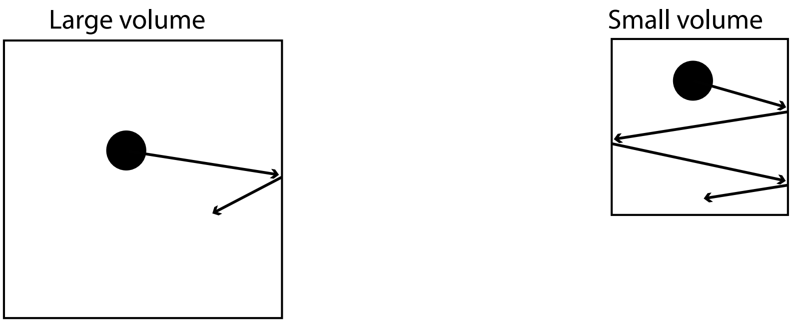
Volume and Pressure (Temperature remains constant)

If the size of the box is reduced (volume is less) then, travelling at the same speed, the atoms



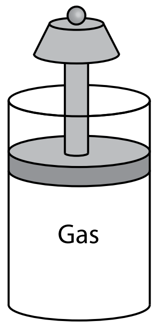
Pressure Law: P is proportional to T

will collide with the walls more frequently as there is less distance to travel.



Boyle's Law: Pressure is inversely proportional to volume (V↑P↓)

Temperature link to Volume (Pressure remains constant)



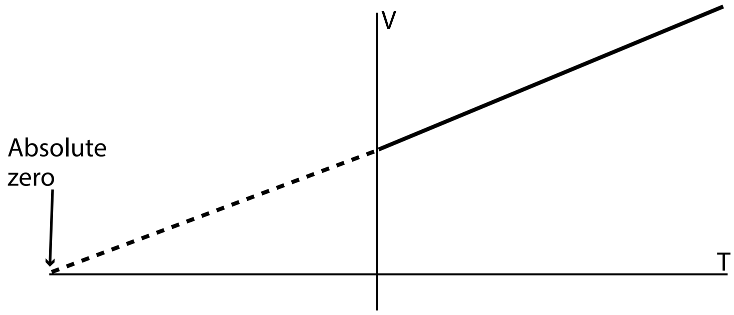
A piston holding in a cylinder of gas will remain at the same position if the force up from the gas pressure equals the force downwards from the weight.

If we heat the gas up the atoms move faster, giving more collisions per second and more pressure, so the piston will move upwards. It will stop when the force upwards again equals the force downwards and the pressure is the same value as before, but with a larger volume.

Charles' Law: Volume is directly proportional to temperature (T↑V↑)

Absolute Zero

If we measure the gas volume in the cylinder at different temperatures we will obtain a graph like this:

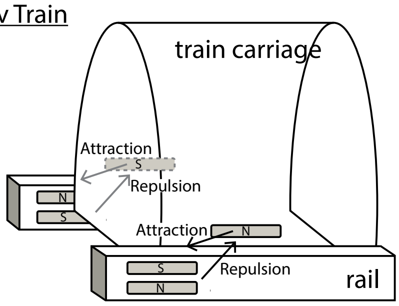


When T = zero Celsius the gas still has volume but if we trace the graph back to where V = zero the point on the T axis is -273°C. This is called **Absolute zero**, where no gas can have a volume because there are no atoms moving in the box.

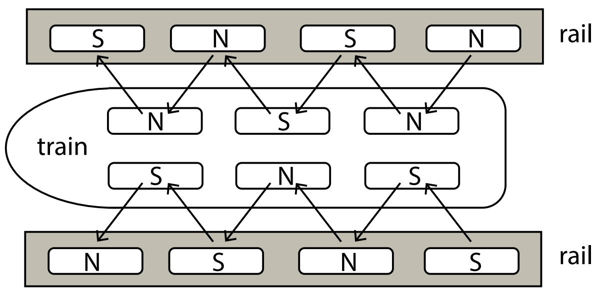
This lack of movement of atoms at absolute zero is made use of in Superconducting substances. These metalloids have a zero resistance below about 90 K and hence can carry very large currents without getting warm. Superconducting magnets are used in MRI machines, magnetic levitation trains and the Large Hadron Collider.

In the Maglev Train, two magnets raise the train above the rails and another set moves the train along by magnetic attraction.

Maglev Train



Electromagnets in the rail attract or repel the magnets in the train to lift it upwards (levitation).

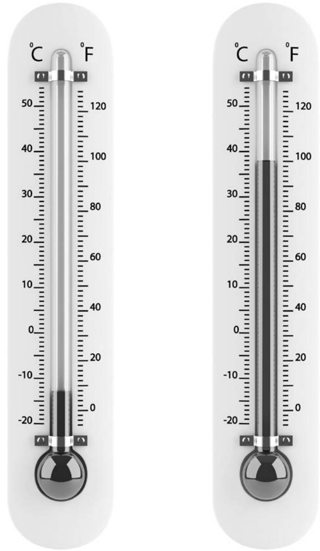


Propulsion: magnets behind repel and magnets in front attract

Zero Celsius is not a true zero — it is only the melting point of ice. If we measure temperatures starting from the true zero (-273°C) then we have the Kelvin Scale of Temperature and V will be directly proportional to the temperature, measured in kelvins. 0°C = 273 kelvins (273 K).

Temperature in kelvins = Temperature in Celsius +273

3.12 Thermometers

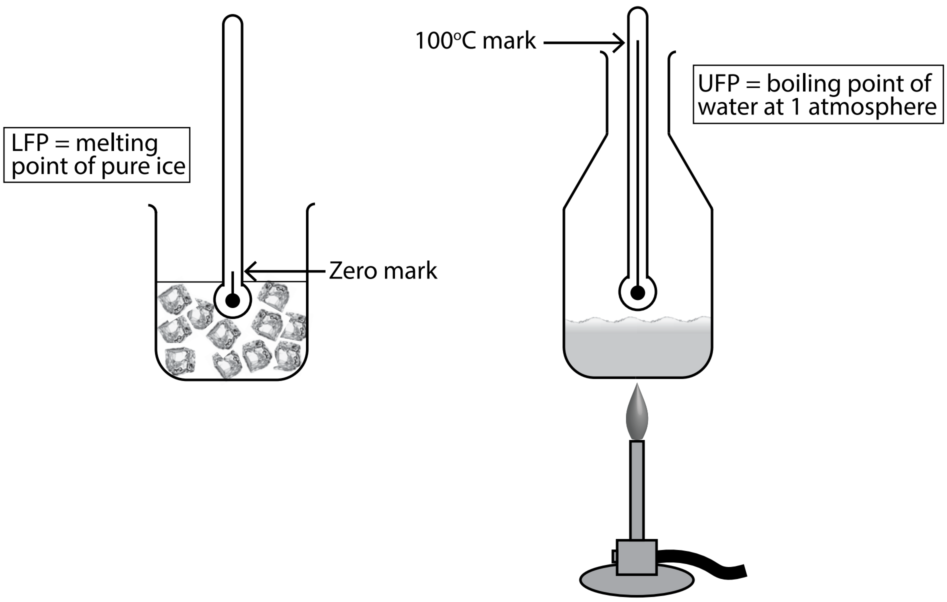


Thermometers use the change in a physical property of a substance to judge temperature e.g. expansion of a liquid, resistance of a conductor.

The thermometers used in schools use the fact that the volume of mercury (or alcohol) increases with temperature to indicate temperatures.

Any thermometer must be **calibrated** (markings put onto it) by referring to defined temperatures. In the Celsius scale the upper and lower fixed points are defined: Upper Fixed Point (UFP) is 100 degrees Celsius – the boiling point of pure water at 1 atmosphere pressure; Lower Fixed Point (LFP) is zero degrees Celsius – the temperature of pure melting ice.

To make **graduations** on the thermometer the distance between the marks for UFP and LFP is divided into 100 parts. Each division is then 1 degree Celsius.



There are other types of thermometers that rely on other properties that change with temperature e.g. change in colour, change in resistance, change in pressure or change in thermocouple voltage. All of these would be calibrated in the same way.

Heating & Cooling Test 1 [40 marks total]

Data on Specific Heat Capacities ($Jkg^{-1}K^{-1}$):

Water = 4180, Copper = 390, Aluminium = 880, Human Body = 3470, ice = 2100

Specific Latent Heat of Fusion of ice = 3.36×10^5 J kg^{-1}

Specific Latent Heat of Vaporisation of steam = 2.25×10^6 J kg^{-1}

PE = mgh g = 9.8 ms^{-2} KE = $\frac{1}{2}mv^2$

Formulas: $H = mc\Delta T$ $H = mL$ $H = Pt$

1.a) How much heat is required to heat 150 g piece of copper up from 20 to 45 degrees?
[2 marks]

b) If a water heater supplies 36 MJ of heat to 280 litres of water at 22°C what will the final temperature be after heating? [3 marks]

2.a) 225 kJ of heat is absorbed from the stove by an empty aluminium saucepan of mass
1650 g. Calculate what the temperature rise of the saucepan would be [3 marks]

b) If the saucepan had contained 350 g of water before heating, what would the temperature rise have been then? [4 marks]

3.a) A gas burner is placed under a beaker containing 330 g of water at 15°C for 2½ minutes. The temperature of the water rises to 77°C. Calculate the heat given out by the gas burner.[3 marks]

b) Calculate the power of the gas burner (heat per second). [2 marks]

c) How long will it be before the water reaches boiling point from 77°C? [4 marks]

4.a) A man of mass 72 kg running in a marathon race starts with a normal body temperature of 37.6°C. At the end of Riverside Drive his body has generated 1.05×10^6 joules of heat. What would be the theoretical rise in temperature of his body? [3 marks]

b) If his body compensated for the extra heat by sweating to remain at a constant temperature, how many grams of sweat (water) would his body have lost for this amount of heat? [3 marks]

5. A copper can of mass 230 g contains 210 g of water at a temperature of 860C. A mass of crushed ice at a temperature of –70C is added to the water and, after stirring, the temperature of the whole mixture was found to be 380C. Find the mass of ice that was added. (Hint: Don't forget to allow for the heating of the copper can). [5 marks]

6.a) An ice tray contains 185 g of iced water at 0^{o}C when it is put into the freezer. If the freezer has a power rating of 285 watts (285 joules extracted per second) calculate how long it will be before all the water has frozen (Hint: find the heat that must be extracted from the water) [3 marks]

b) Steam from a boiler is pumped through a pipe for 2 minutes into a bucket of water containing 4.85 kg of water at 200C. Steam comes through the pipe at a rate of 5.00 g per second. What is the final temperature of the water in the bucket?[5 marks]

Heating & Cooling Test 2

Section A - Multiple Choice

1. Which of the following statements are true when a hot object is brought into a cool room?

   1. Heat is being radiated by the room

   2. The room will heat up by conduction, convection and radiation

   3. The rate of radiation of the hot object will remain the same in the first few minutes

   a) 1 & 3 only

   b) 2 & 3 only

   c) 1 & 2 only

   d) all are correct

   e) 1 only is correct

2. Two different objects are given the same amount of heat. Which statement is true?

   a) Each object will always radiate the same amount of heat

   b) Each object will always be at the same temperature

   c) Each object will have the same temperature rise

   d) The molecules of each object will be vibrating at the same speed

   e) The total energy increase is the same for each object

3. A man fans himself and feels cooler. This can be explained by the fact that:

   a) water has a high specific heat capacity

   b) the air is saturated with water vapour and there is no air flow

   c) the air is not saturated with water vapour, he is not sweating and there is no air flow

   d) the air is saturated with water vapour, he is not sweating and there is air-flow

   e) the air is not saturated with water vapour, his face is sweating and there is air flow

4. Which of the following is most closely associated with the temperature of a body?

   a) the closeness of the atoms

   b) the mass of the body

   c) the volume of the body

   d) the surface area of the body

   e) the motion of its molecules

5. If the molecules of two different gases have the same average kinetic energy,

   a) the volumes of the gases must be the same

   b) their temperatures are equal on the absolute scale only

c) they exert the same pressure on the walls of the containers

d) the temperature of the gas with the larger molar mass (molecular weight) is lower

e) their temperatures are equal on any scale

<u>The next three questions refer to the following information.</u>

4180 joules of heat energy will cause a rise of 1oC in 1 kilogram of water. In an investigation, a student placed a beaker containing 0.5 kg of water over a Bunsen burner for two minutes. The water temperature rose from 19oC to 33oC.

6. The quantity of heat energy that the water received was about

a) 600 J b) 29300 J c) 840 J d) 1040 J e) 147,000 J

7. If only half the heat produced from the burner had been absorbed by the water, the heat given out by the burner would have been about:

a) 15 kJ per minute b) 86 kJ per minute

c) 29 kJ per minute d) 118 kJ per minute

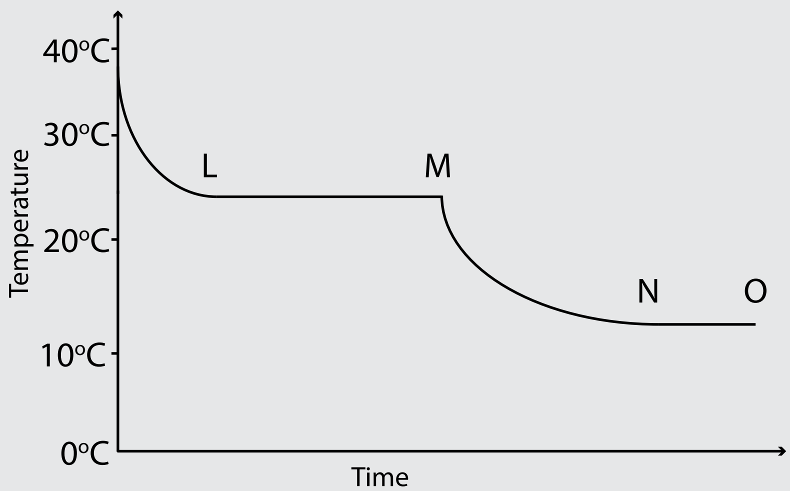
e) 57 kJ per minute

8. The beaker is replaced by an identical one containing 2.5 kg of water at 20°C, and is left on the burner for 10 minutes. The final temperature of the water will be closest to:

a) 14 °C b) 34 °C c) 20 °C d) 48 °C e) 100 °C

9. When both are supplied with the same amount of heat, 100g of copper takes less time than 100g of water for an increase in temperature of 5°C. The best explanation for this is:

a) the volume of the copper is less than the volume of the water



b) the copper is a solid and the water is a liquid

c) copper has a specific heat capacity that is lower than that of water

d) copper has used up less heat than water

e) copper is a metal

The next three questions refer to the following information:

A solid X was heated in a test tube until it melted. As it cooled in air, a thermometer was used to stir it slowly and the temperature was recorded every minute. The results were recorded on a graph, as shown below.

10. The melting point of substance X is:

a) 15 °C b) 40 °C

c) between 25 °C and 15 °C d) between 20 °C and 30 °C

e) below 15 °C

11. The temperature remained constant between L and M because:

a) room temperature had been reached

b) heat energy was absorbed by substance X from the environment

c) no heat was being lost

d) substance X was changing from a liquid to a solid

e) substance X was changing from a gas to a liquid

12. The temperature remained constant between N and O because:

a) substance X was changing from a liquid to a solid

b) heat energy was absorbed by substance X from the environment

c) stirring generated enough heat to keep the temperature constant

d) room temperature had been reached

e) substance X was getting colder, but it was already in a frozen state

13. The rate of evaporation of a liquid depends upon

1 humidity of the atmosphere
2 boiling point of the liquid
3 temperature of the liquid
4 temperature of the surroundings
5 the density of the liquid

a) all of 1 - 5 b) all except number 2

c) all except number 5 d) Only 1,2 and 3

e) Only 2, 3 and 4

14. Advantages of a thermometer containing mercury over one containing alcohol are:

1 mercury is a liquid
2 mercury is a better conductor
3 mercury is denser
4 mercury is opaque
5 mercury has a lower freezing point

a) all of 1 - 5 b) all except number 2

c) all except number 5 d) Only 1, 2 and 3

e) Only 2 and 4

15. An energy efficient house has Pink Batts (fibreglass) above the ceiling with silver foil just below the tiles under the roof. A shiny aluminium foil covered material is often used under the roof of a house because it

a) decreases the amount of convection of heat inside the house

b) helps conduct heat away from the roof

c) decreases the amount of heat transfer through the roof of the house

d) absorbs heat from outside and inside and conducts it away

e) makes the roof waterproof

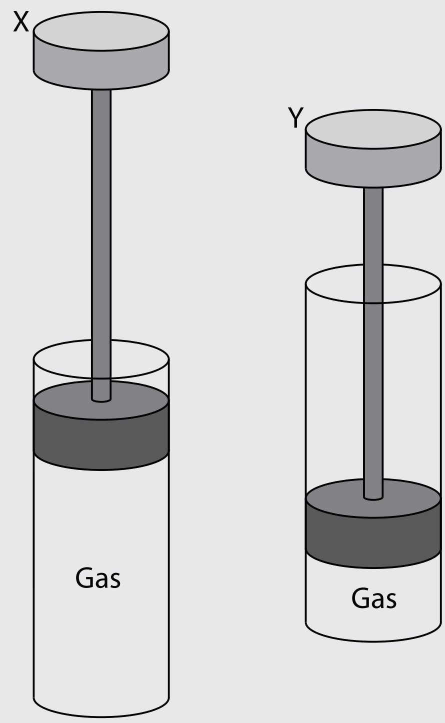
SECTION B (35 marks total)

Formulae and data:

Kinetic energy = ½ mv^2 Potential energy = mgh H = mcΔT

$g = 9.8\ ms^{-2}$ $cw = 4.18 \times 10^3\ J\ kg^{-1}K^{-1}$ $Lv = 2.25 \times 10^6\ J\ kg^{-1}$ $Lf = 3.36 \times 10^5\ J\ kg^{-1}$

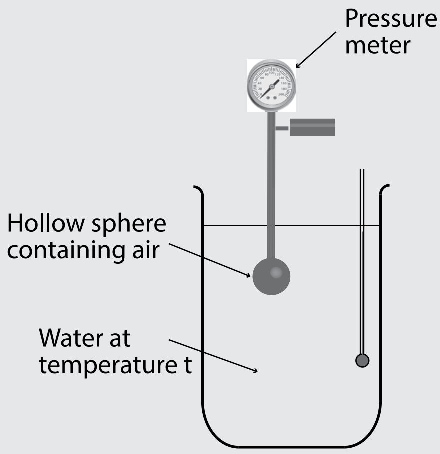
1.a) A syringe containing air at 1 atmosphere pressure (X) is pushed in until it is 1/3 of the original volume (Y). State what differences occur in the gas pressure and explain why [3 marks]



2. An experiment was used to investigate the variation of pressure of a gas with its absolute temperature (T in kelvins = t + 273).

The experimental results of temperature against pressure (kilopascals) are shown below:

t°C	7	27	47	77
P(kPa)	93	100	107	117



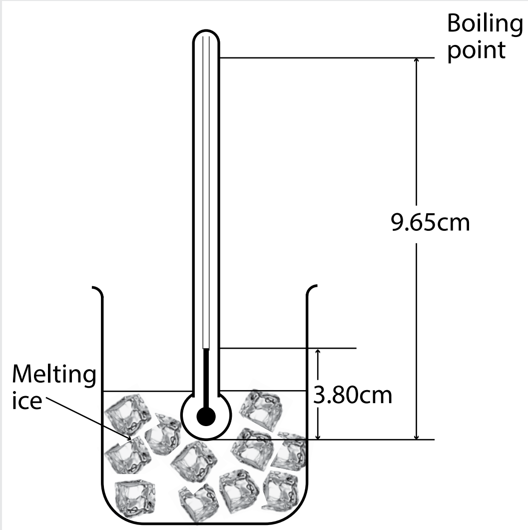
a) What link do these results show between the two variables? [1 mark]

b) Use the ideas of the kinetic theory of gases to explain the results in the table [2 marks]

3.a) Why do ordinary ovens have their heating elements placed at the bottom? [3 marks]

b) Directions for escaping from a burning house are to drop to the floor so you can breathe better. Explain why this could save your life. [3 marks]

4.



An uncalibrated thermometer filled with a black thermometric liquid is shown above while it is at the Lower Fixed Point and attached to a ruler.

a) Explain the terms:

i) Calibrated ________________________

ii) Thermometric ________________________

iii) Lower Fixed Point __________________ [3 marks]

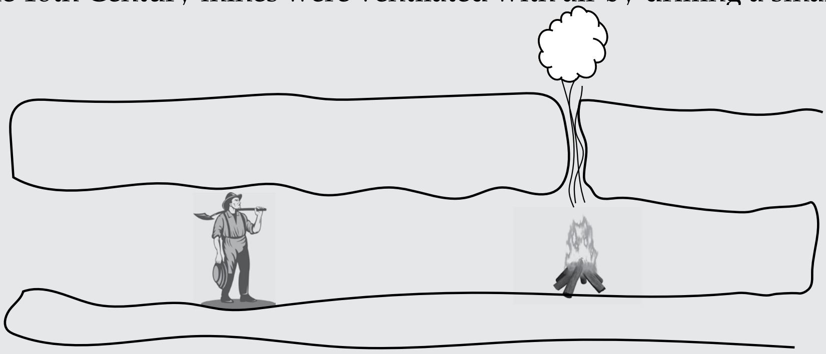
When the thermometer bulb is placed in Lower Fixed Point conditions the liquid reaches a mark of 3.80 cm on the ruler.

When the thermometer bulb is placed in Upper Fixed Point conditions the liquid reaches a mark of 9.65 cm on the ruler

b) (i) What will be the distance between each 1°C mark of the thermometer when calibrated? [3 marks]

(ii) What temperature is indicated when the liquid reaches a point 6.68 cm along the ruler? [3 marks]

5. In the 18th Century mines were ventilated with air by drilling a small extra shaft and



Explain how the fire helps to ventilate the mine. [3 marks]

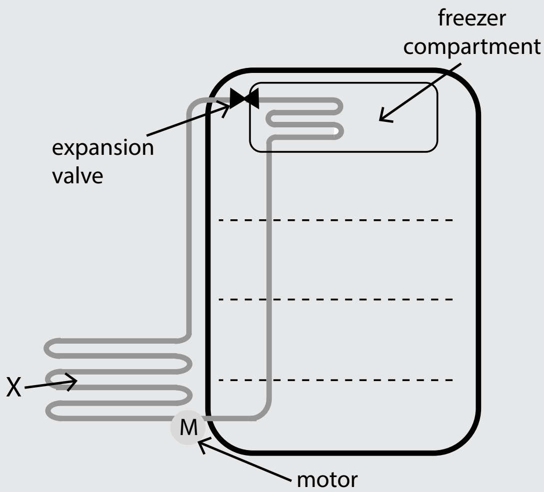
____

____

____

____

Q6. Below is a simplified diagram of a refrigerator system.



a) Draw in arrows to show the direction of flow of refrigerant [1 mark]

b) Name and explain the design of structure X [2 marks]

____

____

____

____

c) Explain how the refrigeration system works, mentioning the function of the motor and the expansion valve. [4 marks]

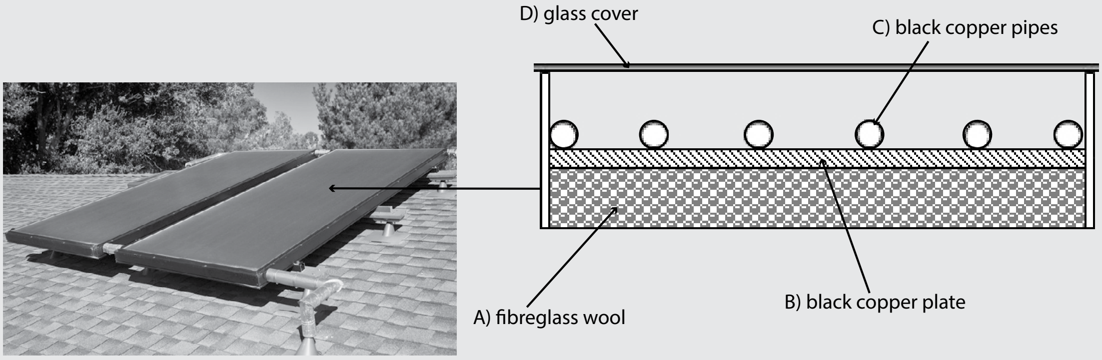
____

____

____

____

7. Shown below is a solar pool heater that uses the sun's light to produce warm water for a swimming pool. A cutaway section of the solar panel is shown on the right.



For each of the four labelled components indicated with arrows (A, B, C, D) state their purpose and how they contribute to the efficiency of the heat transfer process [8 marks]

A ____

____

____

____

____

B ____

____

____

____

____

C ____

____

____

____

____

D ____

____

____

____

____

____